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EFFECT OF HINGE LENGTH ON SENSITIVITY OF PUSHOVER ANALYSIS

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ABSTRACT

Non-linear static pushover analysis is performed under permanent vertical loads and gradual increment in lateral loads. In actual construction procedure, the strength of steel and concrete may vary. The results from the analysis program are significantly sensitive to design parameters. Thus in this study, an attempt is made on a G+2 Reinforced concrete (RC) structure to interpret the sensitivity of pushover analysis by varying the strength of steel, concrete and hinge length on rigid diaphragm slab and comparing the results with experiment results.

Keywords: Sensitivity, Moment-Curvature, Lateral load, Rigid-diaphragm slab

I INTRODUCTION

The intent of Pushover analysis is to assess the expected performance of by analysing its strength and deformation requirements in theseismic design of structure by using Non-linear static analysis and evaluating these requirements to accessible capacities at important performance levels. Non-linear static analysis has made a rapid advancement over the past few decades and now has become amost adopted method for design and seismic performance evaluation as the method is considerably simpler. In recent year, the precision and certainty of pushover analysis in seismic evaluation has been a topic of consideration and progress of pushover method has been suggested to overcome the constraints of the method.

Ashraf Habibullahet. al.,(1998) [1] suggested steps to carry out pushover analysis of a 3-Dimensional structure in SAP-2000, which is fully integrated into the program, allows simple and clear application of the pushover procedures recommended in the ATC-40 [6] and FEMA-273[8] documents for both two and three-dimensional buildings. Mehmet Inel et. al.,(2002) [3] explored about push-over analysis approach for theperformance-based design of thebuilding are progressively changed to account for nonlinear elastic-plastic behavior under consistent gravity loads and by agradual increment of lateral loads.Cosenza, E. et. al., (1998) [4]explained thatDuctility of RC structure relies on thebehaviour of the cracked element, which is well defined by themoment-curvature relationship. Analysis considering the interpretation of a plastic hinge length is very useful. Plastic hinge length (Lp) has asignificant influence on the displacement capacity of the structure.
Much improvisation is required, combined with experimentally obtained results and analysis stressed by S.Elnashai (2001) [2]. But the experimental test results are rarely available to correlate with pushover analysis. In the present study, the analytical results are being correlated with experiment results which were conducted in Structural Engineering Research Center (SERC), Chennai which was conducted by Akanshu Sharma. In this paper, keeping the

basis ofexperimentally obtained results of corresponding base shear and roof displacement, the frame structure is modeled to inspect the sensitivity of pushover curve.

II DETAILS OF STRUCTURE

A basic model is generated in SAP2000 program and as per the experimentally tested structure; material and geometrical properties are assigned.The structure isa RC G+2 storeyed framed structure. The height of floor is 1.8m for all storeys. It consists of two bays of 1.5m spacing in both directions.

2.1 Section Properties

Both beam and column are 150mm× 200mm in size. The main reinforcement for beam was 2-12Φ bars at top and bottom and 2-16Φ bars at top and bottom for the column. The stirrups provided were 2-legged 6Φ @ 150mm c/c. The slab thickness is 50mm. The average concrete strength and average yield stress were found to be 35 Mpa and 478 Mpa respectively.

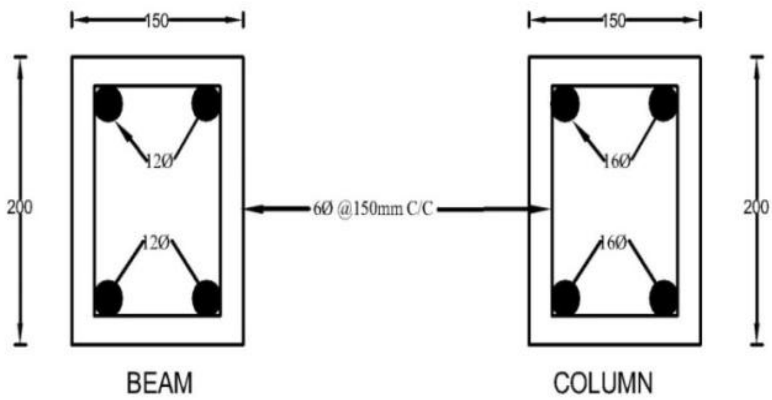
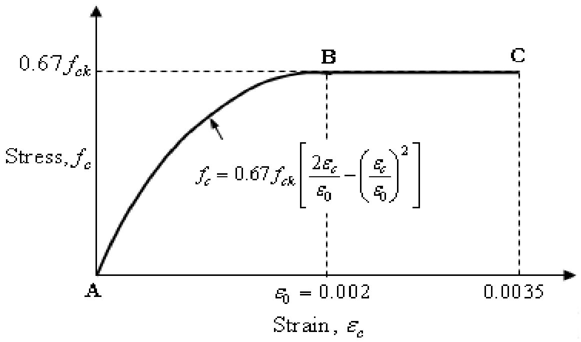


Figure 1: Sectional Properties of Beam and Column

2.2 Modelling Details

Material and geometrical properties are assigned as per the experimental structure and a basic model is generated in SAP2000. Different inbuilt default and user defined plastic hinge options are available in SAP2000 based on average values from ATC-40 [6] and FEMA-273 [8] for concrete members and steel members respectively. As the user-defined hinges reflect elemental nonlinearity behaviour, user-defined hinges are preferred over default hinge options.To use user-defined hinge properties selection moment-curvature analysis of each element is required. Moment-curvature values are generatedbased on amaterial model for concrete and steel. In the present study, IS recommended stress-strain model for unconfined concrete and British code (CP-110-1972) for steel have been adopted as shown in figure 3 and figure 4. The generated values of moment-curvature of beam and column are shown in table 1 and table 2. Moment values are in kN-m.



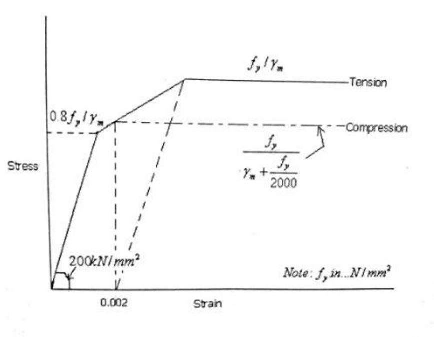


Figure 3: IS recommended stress-strain model for unconfined concrete

Figure 4: British code recommended (CP 110-1972) stress-strain curve for steel

Table 1: Moment-curvature values for beams

Points	A	B	C	D	E
	Origin	Yielding	Ultimate	Strain hardening	Strain hardening
fy= 478N/mm^2 fck=35 N/mm^2	M=0 Φ=0	M=13.8 Φ=0.0126	M=14.04 Φ=0.0748	M=14.82 Φ=0.0801	M=16.9 Φ=0.0951

Table 2: Moment curvature values for columns

Points	A	B	C	D	E
	Origin	Yielding	Ultimate	Strain hardening	Strain hardening
fy= 478N/mm^2 fck=35 N/mm^2	M=0 Φ=0	M=23.0 Φ=0.0148	M=23.9 Φ=0.0915	M=24.92 Φ=0.098	M=27.79 Φ=0.1183

III LOAD PROFILE

After modeling the structure, pushover load cases are defined. Generally, after applying gravity load as the first pushover load case, then following lateral pushover load is applied to start from the final state of gravity loading.Structuresalong the height of the structure are subjected tolateral loads, which are based on the formula in Eq. (1), in FEMA 356 [4], shown below and then incorporated in the model.

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- $$F_x = \frac{W_x h_x^{\,k}}{\sum_{i=1}^{N} W_i h_i^{\,k}} V$$

(1)

- $$C_{vx} = \frac{W_x h_x^{\,k}}{\sum_{i=1}^{N} W_i h_i^{\,k}}$$

Where F_x is lateral load applied at any floor level "x", W is total building weight, h is the floor height, V is lateralloadand N is the number of floors. $C_{vx}$is vertical distribution factor for the lateral load. Using the above equation, the lateral loads were calculated. The lateral loads were applied in the ratio of 9:4:1on each floor as generated by above equation and then applied to the model.

IV EXPERIMENTAL RESULTS

The experimental system used for performing the test is shown below which was carried out at SERC, Chennai byAkanshu Sharma. The RC framed structure was propelled by taking reaction from the reaction wall with the help of servo-hydraulic actuators. The load distribution was parabolic along the height.The experiment was conducted governed by increasing monotonic pushover loads with the load distribution being parabolic along the height of the structure. The maximum base shear and corresponding roof displacement were found to be 286.5kN and 0.110m respectively.

4.1 Analysis

The preliminary analysis was carried out considering the actual material properties of the test results and the framewas modeled as a rigid diaphragm slab was done in SAP2000.From the analysis, it was observed that for therigid diaphragm slab, the corresponding Base shear (P) and Displacement (Δ) was found to be 276kN and 0.172mrespectively.Thus, from the analysis results obtained, it is evident that the experiment results vary to analysis results and are sensitive and susceptible to material and geometric modeling. Further investigation is carried out to check the possible variation in the results obtained from pushover analysis by adopting rigid diaphragm slab model by calculating hinge length using different hinge length properties available in the literature by considering user-defined hinges.Various different formulations have been suggested for calculating the corresponding user defined plastic hinge lengths $L_{p.}$ The length of the user-defined hinge is considered from the following formulations,

1. Park's formula

   L_p= 0.42h

2. Priestly-Park's formula

   L_p = 0.8z+6d_b

3. Panagiotakos-Fardis's formula

   L_p = 0.18z+0.021$d_b f_y$

4. Berry's formula

   L_p= 0.05z+$\left(\frac{0.1 d_b f_y}{\sqrt{f_c}}\right)$

Where,

d_b = diameter of longitudinal reinforcing bars, in mm

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f_y = yield stress of reinforcing bars, in N/mm^2

z = Critical section distance from the point of contra-flexure, in mm

d = effective depth of the cross section, in mm

h = Overall depth of the cross section, in mm

f_c = compressive strength of concrete, in N/mm^2

The experimental results may vary from analytical results where there are chances of variation of the grade of concrete, grade of steel and cover for the reinforcement. But, whereas in analysis, f_y= 478 N/mm^2 and f_{ck}=35N/mm^{2}are adopted. To determine this uncertainty, further study was done by using the same geometric models and by taking into consideration of uncertain properties such as grade of steel, grade of concrete and cover. Adopting lower and upper limits as 15% low and 15% high in reference to the steel grade (f_y= 478 N/mm^2) and concrete grade (f_{ck}=35N/mm^2) a new set of moment-curvature values were generated in excel program and incorporated in the analysis. The comparative graph of pushover curves for different hinge length is shown in figure 4. Table 3 shows results of rigid diaphragm slab model with varying f_{ck} and $f_y$by considering different hinge length properties.

Table 3: Base shear and displacement values for varying fy and fck with various hinge length formulations

1 Lp					Priestly-Park				
Sl.No	f_{ck}	f_y	Base Shear (kN)	Displacement (m)	Sl.No	f_{ck}	f_y	Base Shear (kN)	Displacement (m)
1	29.75	406.3	235.171	0.175279	1	29.75	406.3	232.522	0.04010
2	31.5	430.2	249.579	0.172247	2	31.5	430.2	246.515	0.039704
3	33.25	454.1	261.719	0.171546	3	33.25	454.1	258.621	0.039764
4	35	478	275.589	0.172686	4	35	478	272.070	0.040187
5	36.75	501.9	289.340	0.173131	5	36.75	501.9	285.508	0.040490
6	38.5	525.8	302.829	0.173784	6	38.5	525.8	298.840	0.040818
7	40.25	549.7	317.120	0.059192	7	40.25	549.7	312.790	0.017177
Park					Panagiotakos-Fardis				
Sl.No	f_{ck}	f_y	Base Shear (kN)	Displacement (m)	Sl.No	f_{ck}	f_y	Base Shear (kN)	Displacement (m)
1	29.75	406.3	231.864	0.033272	1	29.75	406.3	232.882	0.045222
2	31.5	430.2	245.757	0.033008	2	31.5	430.2	246.940	0.044728
3	33.25	454.1	257.846	0.033103	3	33.25	454.1	259.058	0.044761
4	35	478	271.146	0.033495	4	35	478	272.486	0.045206
5	36.75	501.9	284.567	0.033790	5	36.75	501.9	286.017	0.045515
6	38.5	525.8	297.826	0.034106	6	38.5	525.8	299.399	0.045855
7	40.25	549.7	312.202	0.015067	7	40.25	549.7	313.390	0.018763

Berry				
Sl.No	f_{ck}	f_y	Base Shear (kN)	Displacement (m)
1	29.75	406.3	233.177	0.050345
2	31.5	430.2	247.278	0.049752
3	33.25	454.1	259.421	0.049759
4	35	478	272.883	0.050225
5	36.75	501.9	286.438	0.050539
6	38.5	525.8	299.838	0.050893
7	40.25	549.7	313.879	0.020349

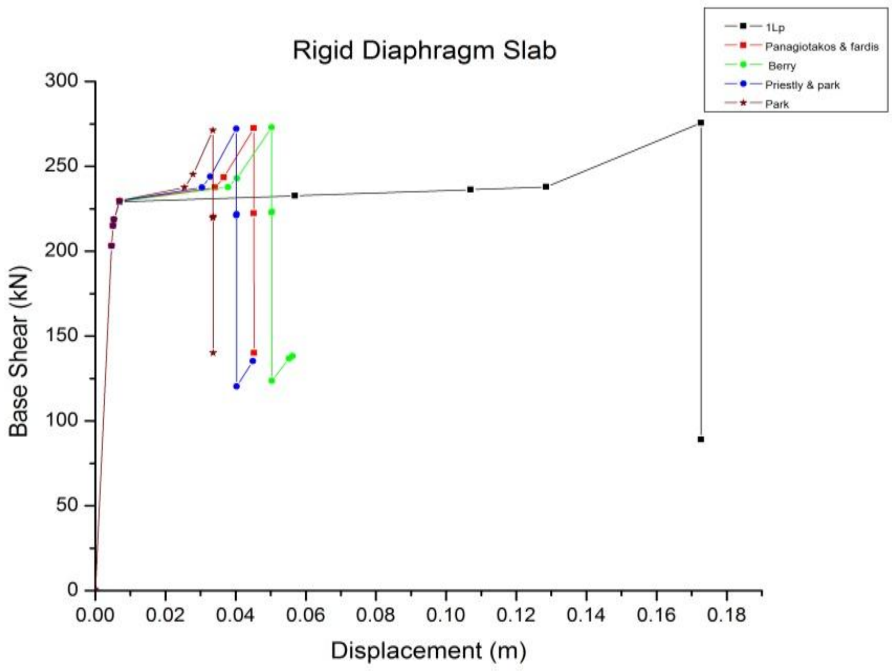

Figure 5: Comparison of Pushover curve for different hinge length (Rigid Diaphragm slab)

V CONCLUSION

- From the analysis, it was found that in all models there was a variation of base shear and displacement results when compared to experimental results. Thus, pushover analysis is sensitive to geometric modelling.
- When compared with experimental values, for the reference grade of materials and cover, the base shear value was 3.89% lower and displacement was 60% higher.
- Considering all hinge length formulations, the base shear values were virtually equivalent with experiment results but the displacement was furthermore low. The variation shows that further improvement is necessary for pushover analysis.

- Beams and column joints were modelled by means of hinges at the concentrated ends to beam and column. The non-linear performance of joint core is necessary to find the complete performance of the frame analysed.
- Further, frame with shell slab can be considered and compared with rigid diaphragm frame.

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